Propose of Architecture Design for Early Warning System with Space and Terrestrial Infrastructure

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Abstract—**The purpose of this research is to design the architecture of an early warning system with Global Navigation Satellite System (GNSS) and terrestrial infrastructure for improving coverage of disaster information dissemination. In the proposed architecture, necessary segments and information flow are identified to introduce an early warning system to target areas which lack public alert distribution. It can be adapted worldwide by combining GNSS satellite and terrestrial infrastructure. At the beginning of a disaster, information will be sent from the agency via GNSS to widely used terrestrial infrastructure, such as sirens and public vehicles, thus allowing users to receive disaster information even when the ground network has been damaged. The effectiveness of the proposed architecture is examined in terms of redundancy, interoperability, and multi-hazard response by Geographic Information System (GIS) simulation using an open-source format data of public bus in a coastal area of Japan. Results show that the coverage of information dissemination is improved. Thus, the proposed architecture can be adapted to target areas as an early warning system.**

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1. INTRODUCTION

In recent years, large-scale disasters have occurred frequently around the world. Consequently, great attention has been paid to early warning systems. According to the Sendai Framework for Disaster Risk Reduction 2015-2030, the availability of and access to multi-hazard early warning systems and disaster risk information should be increased. Some indicators defined included the number of countries that have a multi-hazard monitoring and forecasting system, as well as the number of people per 100,000 population that are covered by early warning information through local governments or through national dissemination mechanisms [1]. However, countries most vulnerable to the impact of disasters often have the lowest early warning capabilities. In the case of earthquakes, only a few countries have public alert distribution where the alerts are broadcast through multiple channels such as smartphones, while many earthquake-prone regions have limited alert distribution, some of which are still under construction [2]. Therefore, there is a need for cooperative strategies and frameworks to develop a multi-hazard early warning system in high-risk, low-capacity countries [3].

One of the challenges in achieving this goal is improving the dissemination network, especially to ensure redundancy, interoperability, and a multi-hazard response capability [4]. Development of ground communication networks is needed, but these may be damaged when a large-scale disaster happens. When this occurs, people may not be able to get required information such as a disaster alerts or evacuation orders. The usage of satellite systems, which would not be affected under those circumstances, will therefore provide better means of communication. One of the potential tools in this scenario is a satellite phone using communication satellites. However, satellite mobile phones are not widely used by individuals, so it is not appropriate as a means of providing information to everyone. On the other hand, technology that provides mobile phones which have Global Navigation Satellite System (GNSS) receivers with information from satellites directly has attracted attention.

Ongoing research about methods of distributing disaster information by superimposing the information on the augmentation signal of the GNSS satellite exists. In this approach, the information can be distributed to GNSS receivers. These receivers are widely used in, for example, mobile phones, and many people will thus be able to obtain information in this way. The concept design of disaster notification messaging services based on Global Navigation System (GPS) has been discussed [5]. Europe has been working on alert message services using GNSS, proceeding with a standardization activity to define an alert message protocol within the frames of European Geostationary Navigation Overlay Service (EGNOS) and Galileo [6]. In Japan, investigations on transmitting alert message to mobile phones with GNSS functionality using the augmentation signal of the Japanese Quasi Zenith Satellite System (QZSS) are underway [7].

In this study, we propose an architecture of an early warning system that combines GNSS and terrestrial infrastructure for improving coverage of information dissemination at the beginning of a large disaster. In our architecture, terrestrial infrastructure such as a siren and public vehicle, receives an alert message from GNSS and delivers it automatically. People will be able to receive the information through our system, even those without a mobile phone. The architecture integrating GNSS and terrestrial infrastructure, both of which can be used worldwide, also helps to introduce early warning systems, especially to places which need but still do not have them. Combining space and terrestrial networks achieves redundancy, interoperability and multi-hazard response, and can help to introduce more early warning systems around the world. As a first step, we evaluated the effectiveness of our architecture in terms of coverage of information dissemination by Geospatial Information System (GIS) simulation using the open-source data from the public bus network in a coastal area in Japan where the existing outdoor siren system cannot fully cover the area of information dissemination.

2. Proposed Architecture

The proposed architecture is shown in figure 1. As a result of comparative analysis of several early warning system architectures such as a Tornado Warning System in United States [8] and the J-Alert System in Japan [9], four main subsystems are identified: Information Collection Agency, Alert Delivery Agency, Disaster Manager in Administrative, and Service Provider. The interface between the above four subsystems and a satellite segment is identified based on previous research [10]: GNSS, GNSS Master Control Center.

One of the features of the proposed architecture is the utilization of terrestrial infrastructure as a means of broadcasting disaster information. The advantage of using terrestrial infrastructure is that the infrastructure is set or moves near many people such that it typically delivers information widely, rapidly, and with certainty at the onset of a disaster. Some sirens or public vehicles already have their own battery and the system will thus work even when the ground communication infrastructure is damaged in the disaster. We assume that the cost of setting and managing this system will be lower than that of other early warning systems outside of buildings siren. This is because only the receiver and conversion program is newly needed to attach to existing terrestrial infrastructure in our architecture.

The information flow in the proposed architecture is shown below. After the disaster happens, the information collection agency collects disaster information and sends it to the alert distribution organization. The organization creates an alert message from the information and sends it to the service provider, the disaster manager in the administration, and the GNSS master control station. The control station converts the message into data and sends it to the GNSS satellite, and it is then distributed to the terrestrial infrastructure. The received data is converted into the alert message and automatically distributed. People can receive the message even if the ground network has been damaged or they do not have an individual device such as a smartphone. The segments and networks of the architecture are adaptable to target areas that need early warning systems so that redundancy is ensured through both space and terrestrial networks, interoperability is

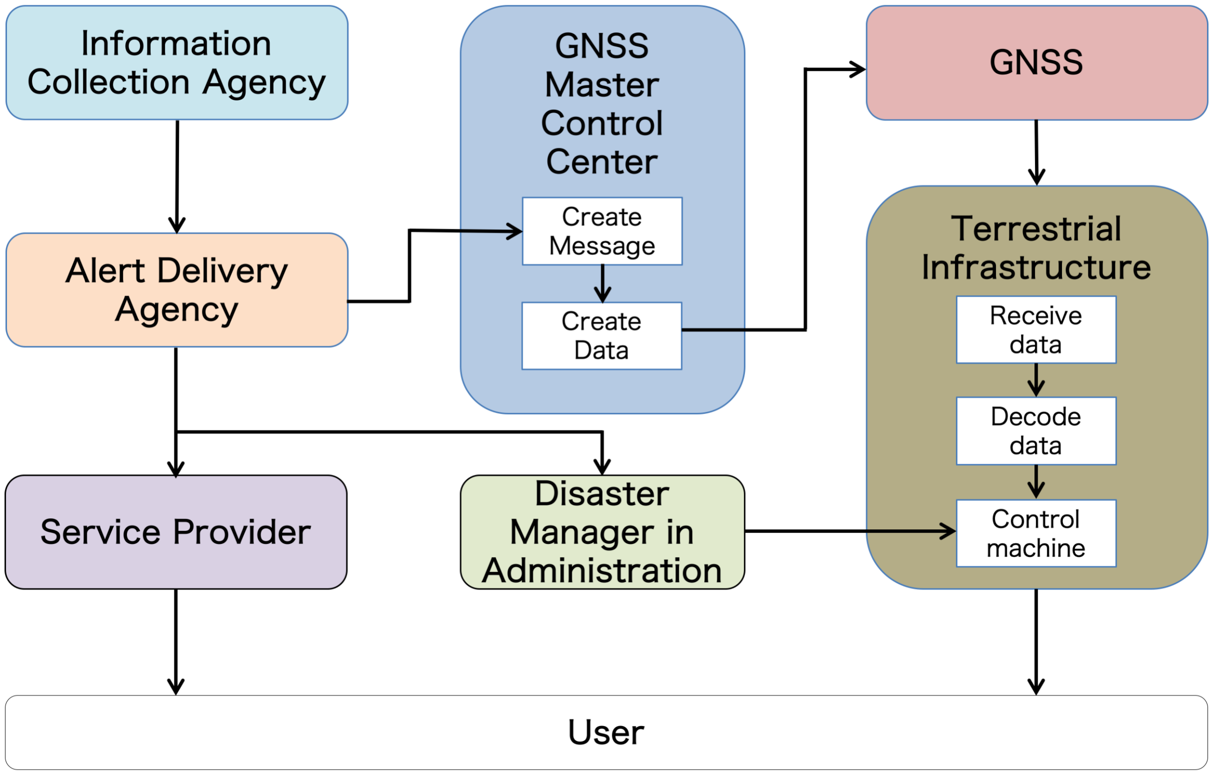

Figure 1. Proposed Architecture

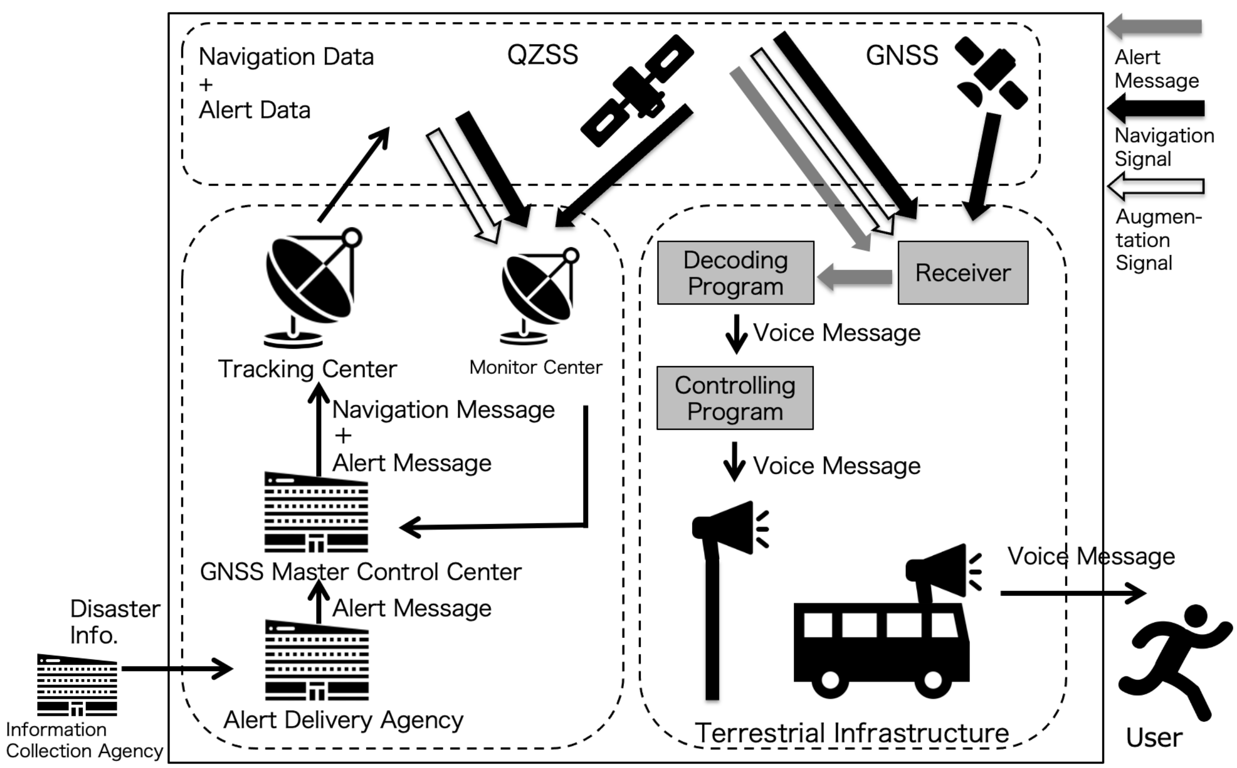

Figure 2. Prototype of the segment of GNSS and terrestrial infrastructure in the proposed architecture

ensured by the worldwide coverage of GNSS and multi-hazard response is ensured by various kinds of terrestrial infrastructure. Therefore, the proposed architecture can bring about the introduction of early warning system to target areas by overcoming the challenge of improving the dissemination network.

3. SIMULATION

In order to evaluate the effectiveness of the proposed architecture, we first made a prototype system (Figure 2). This prototype mainly focuses on the segments of GNSS and terrestrial infrastructure, and is to be used in Japan. This system consists of three segments: dissemination, receiving and satellite segments. The dissemination segment is composed of the Information Collection Agency (e.g., Japan Meteorological Agency and Local Governments), the Alert Delivery Agency, the GNSS Master Control Center, the Monitor Center, and the Tracking Center. The Monitor Center and the Tracking Center are part of GNSS. The dissemination segment transmits alert messages to the satellite segment in the following order. First, the Information Collection Agency gathers disaster information released by the Meteorological Agency and local governments. Second, the Alert Delivery Agency converts the disaster information to an alert message for dissemination by GNSS in the selected message format. The Alert Delivery Agency decides the distribution schedule for providing the information and transmits the alert message to the GNSS Master Control Station. Third, the GNSS Master Control Station collects the Monitor Center results and generates a navigation message. The GNSS Master Control Station uplinks both the navigation message and alert message to GNSS via the Tracking Center.

The satellite segment refers to GNSS. The augmentation signal with the navigation message and the superimposed alert message are generated and then transmitted to the receiving segment. In a prototype system, we focus on QZSS as the main part of GNSS.

The receiving segment is based on terrestrial infrastructure equipped with GNSS receivers capable of receiving the augmentation signal. We assume two types of terrestrial infrastructure: moving objects such as public vehicles and dispersively distributed objects such as vending machine. The receiver receives the data of the augmentation signal and position information from GNSS. The augmentation signal contains the alert message, which is decoded by a decoding program and converted to a voice message. The controlling program controls speakers attached to terrestrial infrastructure to play the voice message automatically so that the user receives the disaster information. The receivers simultaneously acquire the alert message and position information from the satellite so that users can receive disaster information corresponding to the position of the user and the type of disaster.

We simulated the information dissemination from terrestrial infrastructure in the situation of adapting this prototype. The target area is Wakayama city in Japan, one of the coastal areas expected to be affected by the Nankai Trough Earthquake. We acquired the position data of outdoor sirens from open data available from the city. In the simulation, a public bus is defined as terrestrial infrastructure, and the information on the route and the stop are shared in the format of General Transit Feed Specification (GTFS) [11]. GTFS is an open-source transit data format developed by Google to improve availability of public transportation infromation and is currently shared by over 1500 agencies worldwide. There are two types of data formats, GTFS-Static and GTFS-Realtime. GTFS-Static is composed of static data such as schedule and geographic information, while GTFS-Realtime is updated in real time according to the bus operation status. Wakayama city shared both types of data, and we first use GTFS-Static data for the simulation. We input GTFS-Static data of the city to ArcGIS, one of the major GIS software platfroms. By using the Bus Information Search Template, an extension of ArcGIS, the time schedules, bus stops and routes are visualized. The position data of sirens is also input to ArcGIS and the information dissemination from each siren is simulated by buffer processing. The radius of each circle is 300 m because the reach of a message from a siren is within 300 m [12].

One of the reasons for focusing on outdoor sirens in this simulation is that they have a very high reach and a high attention value compared to other methods. There are cases in which mobile phones are not appropriate as a means of receiving information, because not everyone carries a mobile phone all the time and in all kinds of target areas. There are some areas, however, where residents would hardly hear a message broadcast by sirens because the sirens are set too far away [13]. In case of the Netherland, sirens are also used for warning citizens, but previous research shows that an average of 37% of people did not hear the siren on three different test occasions [14]. Therefore, we assumed that the blank area of siren in

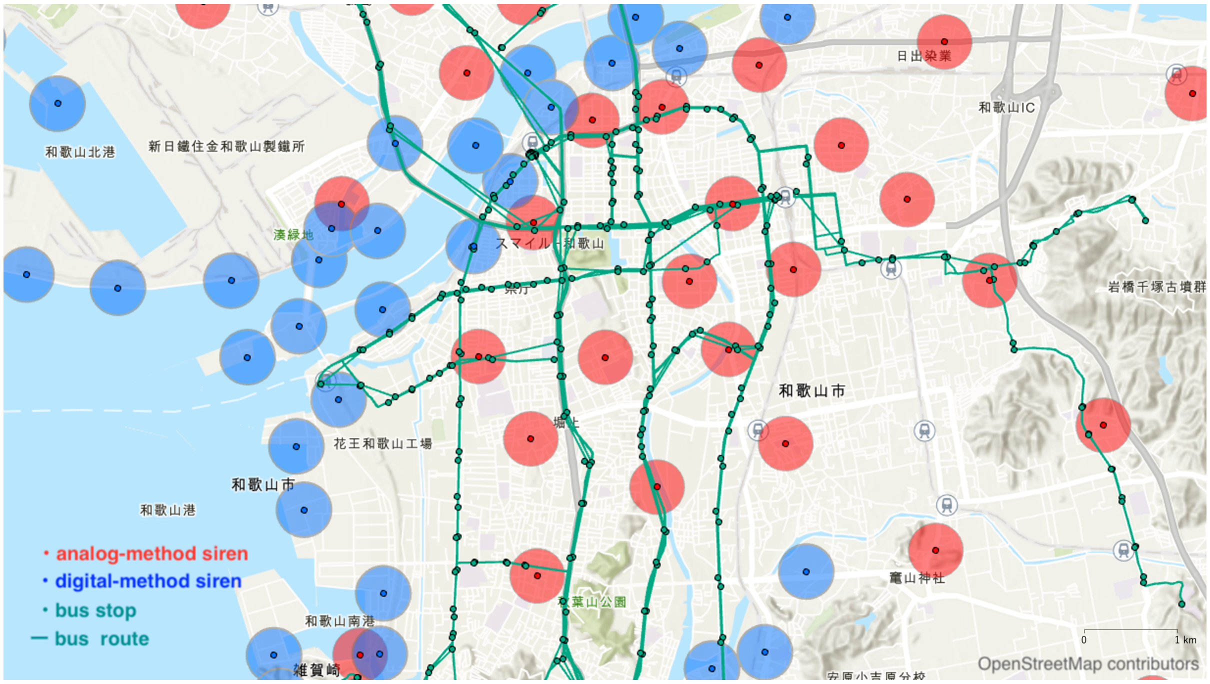

Figure 3. Simulation Result of information dissemination from siren and public bus route in Wakayama city

Wakayama city as a target area that should be introduced early warning system by adapting the proposed architecture.

4. RESULTS

Figure 3 shows the result of GIS simulation. Positions of all sirens in Wakayama city are visualized as colored dots. Red colored dots mean an analog method sirens and blue means the digital method sirens. The difference between the two methods means the difference in frequency of audio information broadcast from each siren. GTFS data input to ArcGIS is visualized as green lines indicating the route of a public bus and green points indicating the position of each bus stop. Each circle shows the information dissemination area from each siren. There are some blank areas without information dissemination from a siren. We can say that an early warning system has not yet been introduced in the blank areas. There are bus routes and bus stops in the blank area. It means that a public bus as terrestrial infrastructure may be an effective means of information dissemination as part of an early warning system. When a large disaster occurs in this city, all public buses will stop moving so that they can be additional sirens to improve the coverage of information dissemination under the proposed architecture. The results also shows that this simulation using GIS software and open data format, can be adapted to other areas where the same kinds of data are acquired, so that the effectiveness of the proposed architecture is similarly verified in the target areas.

We also confirmed that the alert message was actually received, and the voice message was broadcast automatically by demonstration of the prototype using QZSS satellite. After showing demonstration of the proposed architecture, some stakeholders of disaster management agency in target areas gave feedback stating that this architecture would be useful for introducing an early warning to their countries while some subsystems in the architecture do not exist yet. Combining the results of simulation and demonstration, it can be said that the proposed architecture can adapted to the target areas and that it works effectively as an early warning system.

5. DISCUSSION

Simulation revealed where the disaster information broadcasting coverage area can be improved using a public bus in the proposed architecture. The effectiveness of using a bus in this instance is limited by the route and time of travel in a day. We will continue the simulation to calculate the time-series change of the coverage rate of information distribution according to the bus operation by using GTFS-

Realtime data. After identifying the blank area or blank time of information transmission in the area, we can discuss what other kinds of terrestrial infrastructure should be applied including existing one such as other types of vehicle or additional ones such as drones. The GTFS format we used this simulation is widely used worldwide, meaning that we can apply this simulation to target areas in other countries. We will simulate the proposed architecture in another Asian and Oceania countries to identify appropriate terrestrial infrastructure in the areas, and then test the prototype in actual areas by using QZSS and other GNSS satellites. In the test, all flow of information in the proposed architecture will be demonstrated by both space and terrestrial networks so that the three defined requirements of redundancy, interoperability and multi-hazard response can be validated. It may encourage consideration of realistic actions to introduce an early warning system to the target area.

From the result of the simulation it appears that terrestrial infrastructure should be controlled according to its position so as to avoid congestion of information dissemination. In the proposed architecture, an additional function of automatic control of terrestrial infrastructure based on its position data acquired by GNSS may be needed. In an real life situations, messages broadcast from sirens are sometimes affected by buildings or mountains, so 3D modeling will be required as part of the GIS simulation. Additionally, mobile data is needed to visualize the flow of people outside buildings. We will collaborate other institutes in target areas to acquire data for this simulation and also to discuss a prototype test. The feedback we got from some agencies shows that the communication and collaboration between agencies is strongly needed in the proposed architecture, including across countries, especially in case of large disasters. The proposed architecture will finally be validated in some target areas by clarifying how many people in the areas can get more disaster information and what kind of collaboration with each institute should be realized to introduce an early warning system to the areas.

6. SUMMARY

In order to improve the coverage of the disaster information distribution, we designed the architecture of early warning system combining GNSS and terrestrial infrastructure. In the architecture, segments and information were identified to introduce an early warning system to the target areas which need, but still does not have, such systems. By combining GNSS satellites and terrestrial infrastructure redundancy, interoperability and multi-hazard response will be realized, and information dissemination will be improved. Verification was conducted using a prototype system, and GIS simulation was employed for evaluation of the coverage of information dissemination. We will keep discussing the approach with stakeholders in local governments and GNSS agencies in Asia and Oceania regions for validation of the proposed architecture in terms of introducting early warning systems.

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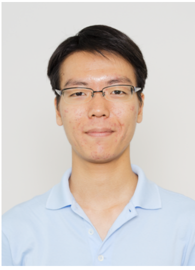
BIOGRAPHY



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